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ALTERNATIVE FRAMEWORKS OF HEAT AND TEMPERATURE: A CRITICAL BARRIER TO LEARNING SCHOOL SCIENCE

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by
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The development of the concepts of heat and temperature in school-age children has been extensively studied (e.g., Erickson, 1979, 1980; Shayer and Wylam, 1981; Stavy and Berkowitz, 1980, and Tiberghien, 1980) so that children's ideas about heat and temperature are relatively well known. However, little is known about the effects of these ideas on a child's capacity to learn the scientifically accepted view of these concepts. Teachers and curriculum developers appear to assume that presenting evidence of the accepted view will result in the student embracing that view. Recent studies (Gilbert, Osborne and Fensham, 1982; Hewson and Hewson, 1983; Osborne and Wittrock, 1983; Pope and Gilbert, 1983; and Stewart, Finley and Yarroch, 1982) suggest that this assumption may not be valid. This paper will discuss a case study conducted in a grade nine science class, as the students learned about heat and temperature.

The broad aims of the study were to investigate:

1) the students' initial beliefs about heat, temperature, and matter,
2) the interaction between those beliefs and the instructional process, and
3) the changes in students' beliefs following a science unit on heat and temperature.

The study was conducted in a secondary school in a middle class neighbourhood, where most of the students spoke English as their first language. The school operated on the semester system. The science class met daily and periods were one hour

in length. There were 9 boys and 14 girls in the class, which was taught by a female teacher. The teacher had several years of teaching experience and had completed a master's degree in biology.

The investigator attended the class for ten weeks, in the role of a non-participant observer. During the first week a pretest (derived from Shayer and Wylam, 1981) was administered to identify the students' initial beliefs about heat and temperature. Eight target students (four female and four male, chosen to represent a cross section of ability levels and achievement) were selected for special attention. These students were interviewed following the pretest to obtain a more in-depth understanding of their beliefs. The final two weeks of the observation period were devoted to the heat and temperature unit. During those two weeks all classes were audiotaped and the tapes were later transcribed. The investigator made notes during the classes, paying particular attention to activities of the target students, and to recording the names of students who spoke during class discussions. All written work completed by the students (lab reports and assigned questions) was reviewed by the investigator, and photocopies were made of work done by the target students. A check-list was prepared to summarize the responses of all other students. On the final day the post-test and the teacher-made unit test were administered. Interviews were conducted with the teacher.

Content analysis of the textbook and curriculum guide led to the identification of six major topics in the unit. Analysis of the student data, as outlined above, identified many ideas which were then grouped under the major topics. The topics and ideas are presented in the Appendix.

The terms "heat" and "temperature" are used in daily conversation, and often in a way that could lead to incorrect ideas about heat. For example, we speak of keeping heat and cold "in" or "out" of places, as if heat and cold were physical substances. Many alternative beliefs about heat have been discussed in the papers referred to above. To illustrate, this paper will examine one alternative belief--the idea that when thermal expansion occurs it is because the particles (atoms or molecules) have expanded. This belief is not uncommon, and was expressed by nine of the 23 students on the pretest and/or in class. Because the question, "Do particles expand when matter is heated?" was not asked directly, we cannot be certain about the beliefs of those who did not mention particles when explaining thermal expansion. However, there were only three students who made no mention of either particles, atoms or molecules on either the pretest and/or the pretest interview. On the posttest, five students still expressed the belief that the particles expand when matter is heated.

The authors of the textbook (Schmid and Murphy, 1979) recognized that many students believe that particles expand. Student questions in the textbook address the idea on two

occasions. First, with respect to a demonstration of the effects of heating a bimetallic strip, they ask:

> When you heat a solid object,
>
> a) what happens to the size of its particles?
> b) what happens to the mechanical energy of its particles?
> c) what happens to the spaces between its particles?
>
> (Schmid and Murphy, 1979, p. 112)

The review questions at the end of that chapter again refer to spaces:

> What happens to the spaces between the particles of air when air is heated? How does this change the density of the air? Explain your answer. (Schmid and Murphy, 1979, p. 125)

The suggested answers provided in the teachers' guide (Schmid and Murphy, 1980) indicate that the students should respond that the spaces between the particles become larger. It would appear that the authors felt that they could better emphasize the lack of expansion of particles by indicating that the spaces become larger, rather than saying the particles spread apart.

The expansion of particles was discussed in class on two different days. The teacher also emphasized the idea that the spaces, not the particles, expand. On the first occasion an investigation to measure temperature using a mercury thermometer was being discussed. Jane, the highest achieving student in the class, was asked what happened to the mercury

when the thermometer was put in boiling water. The discussion continued as follows:

Jane: Umm, it gets heated up and the particles move faster and farther apart and so it has to expand.

Teacher: (*writing on overhead projector*) O.K. We'll put that down. When mercury is warmed or heated up, I'm finding it hard to hear (*closes door to hallway*). Now, what did you say happens to the particles, Jane?

Jane: The particles speed up and moved farther apart.

Teacher: Are the particles themselves getting bigger?

Several Students: No

Teacher: What's getting bigger?

Students: The spaces.

Jane: The spaces between the particles.

Teacher: O.K. So the spaces are getting bigger. What's happening to the quantity of mercury? The volume of it?

Male Student: Stays the same.

Teacher: Lynne?

Lynne: The volume's increasing.

Teacher: The spaces are getting bigger. The particles stay the same size, but the spaces get bigger. The whole quantity has an increase in volume.

Female Student: The volume increases.

Teacher: And what do we call that? When we say the volume increases, the mercury?

Student: Expands.

Teacher: So it sounds like the particles are getting bigger. They're not really. The whole blob of mercury in the bulb of your thermometer expands. Where does it go?

Jane: Rises up the tube.

(Teacher points to Susan).

Susan: Goes up the tube?

Fifteen minutes later the teacher performed the ball and ring demonstration for the class and asked:

Teacher: What's happening to the particles inside the ball as I heat it?

Several students: Expands.

Teacher: Careful now. Listen to the question. What happens to the particles? Susan?

Susan: The particles are expanding.

(several hands raised)

Teacher: Are they?

Students: Nooo.

Teacher: Jane?

Jane: They're speeding up and moving apart.

Teacher: How do they speed up? What kind of energy are they gaining?

Students: Heat/Mechanical.

Teacher: They're moving farther apart and what's expanding?

Students: The spaces.

Teacher: The spaces and therefore the whole ball....

Three days later, Brian, a student who had talked about particles expanding during the pretest interview, was asked if particles get bigger when a metal strip is heated. Brian said he wasn't sure. The teacher then gave a lengthy explanation of why it was impossible for the particles to get bigger. The explanation gradually evolved unto a somewhat different issue and Brian's uncertainty was not dealt with. In the assigned questions for the chapter both Susan and Brian said that particles expand. Susan's response to part a) of the question

quoted above was, "The particles between the air expand..." All other students (including those who later said that particles expand when matter is heated) responded that the spaces would become larger. Another question in the same assignment asked how adding more heat energy to the air in a balloon would change the force of air on the inside of the balloon. Brian responded, "It expands the particles making more room." When the assignments were returned to the students it was indicated that these statements were not correct. Yet, on the post test Susan said that when liquid in a tube is heated and rises in a tube it is "because of expanding particles." On another question Brian replied that heat causes pipes to expand because "it expands their particles." Thus, although all of the students apparently accepted the idea that the particles move farther apart (and/or alternatively, that the spaces expand) when matter is heated, there were at least five students (and possibly others) who did not give up their belief that the particles expand. We can only speculate as to why each of these students persisted in this belief. Some of the students were considered by the teacher to be weak students who had difficulty in science. These students may have simply been so confused by these ideas that they were not aware of any contradictions. Susan and two of the other girls may have had this difficulty. The fourth girl was considered to be an average student. She was not one of the identified target students and did not participate in class discussions, so it

was impossible to even speculate as to why she had difficulty with this idea. Brian's case is somewhat different. Brian was one of two boys who challenged the particle model used in the text. The model is summarized as follows:

> In your last science course, you used the particle model of matter. According to this model, all materials are collections of very tiny particles that are always moving as shown in Fig. 3. The particles of a material stay together because they are always moving in all directions. The spaces between the particles contains nothing; it is a perfect vacuum. (Schmid and Murphy, 1979, pp. 350 and 352)

Brian and Tom persistently argued that atoms and molecules are not single particles and are not the smallest particles of matter. This issue particularly surfaced with respect to the idea that heat energy is the energy of the particles (one of the key points made in the textbook). Students were told that, unlike other energy transformations, there was not heat lost due to collisions among particles. The teachers' guide warns the teacher that problems may occur with this model.

> The statement that gas particles have nothing smaller to give their energy to is a simplification of the facts. Thinking students may know that many particles are made of atoms which, in fact, are made of smaller particles still. ...However, because the number of component parts of a particle is small (compared to the number of component particles of a macroscopic object) energy can be given back by the component parts to the particle as a whole. In contrast, the chance of energy being given back to a large object by its particles is practically nil. (Schmid et al, 1980, p. 106)

When the teacher tried to present this view in class it simply was not accepted by either Brian or Tom. Both "knew" that

neither an atom nor a molecule consists of a single particle. The investigator suspects that Brian may have assumed that the protons, neutrons and electrons could move farther apart, thereby causing the atom to expand. Unfortunately, there was no opportunity to verify this speculation. It would however, account for his persistence in the idea that particles expand.

This paper has provided a brief example of one approach to the analysis of student ideas about heat and temperature. It illustrates the wealth and depth of data that can be obtained in a relatively short time, in one rather small class, using intensive data collection techniques. Such studies can serve to enlighten teachers and curriculum developers about the thinking of science students and can identify some of the learning barriers students carry with them when they come to study science.

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APPENDIX: STUDENT IDEAS ABOUT HEAT AND TEMPERATURE

Topic I: The Particulate Nature of Matter

Idea 1.1. All matter is composed of particles.

Idea 1.2. The particles of matter are in constant motion and therefore have mechanical energy.

Idea 1.3. The spaces between the particles are a perfect vacuum.

Topic II: Heat Energy and its Effects on Matter

Idea 2.1. Definitions of heat energy:

2.1.1. The heat energy of an object or of matter is the sum of the mechanical energy of the particles in the object or matter.

2.1.2. Heat is a form of matter and consists of particles.

2.1.3. Heat is something that moves between the particles of matter.

2.1.4. Heat is something that pushes the particles of matter.

2.1.5. Cold is a distinct thermal entity.

Idea 2.2. When matter is heated/cooled many changes in the matter can be observed.

2.2.1. The temperature goes up/down.

2.2.2. Matter expands/contracts.

2.2.3.. Matter rises/falls.

2.2.4. Matter softens, melts, liquifies, boils, evaporates/hardens, freezes, solidifies, condenses.

2.2.5. Matter gets heavier/lighter.

Idea 2.3. We make inferences about the behaviour of particles when matter is heated/cooled.

2.3.1. Particles move faster/their mechanical energy increases/they

hit one another more.

2.3.2. Particles are farther apart/their spaces expand.

Topic III: Temperature and How it is Measured

Idea 3.1. Definitions of Temperature

3.1.1. Temperature is a measure of the average mechanical energy of the particles.

3.1.2. Temperature is the hotness or coldness of an object or of matter.

3.1.3. Temperature is a measure of the heat of an object or of matter.

Idea 3.2. The characteristic property of thermal expansion allows us to use the volume of a fixed amount of matter to indicate the temperature of that matter.

Topic IV. The Difference between Temperature and Heat Energy.

Idea 4.1. The amount of heat energy contained in matter depends on: the kind of material; the amount of matter; and the temperature of the matter.

Idea 4.2. When matter is heated the rate at which the temperature increases is not constant when a phase change occurs.

Topic V. Heat Transfer

Idea 5.1. Conduction is the transfer of heat energy that occurs when faster particles make nearby particles speed up by hitting them.

Idea 5.2. Convection is the transfer of heat energy by a hotter fluid moving to a colder place.

Idea 5.3. Infra-red rays, like light rays, are a form of

electromagnetic radiation that travel through space. They can be reflected and refracted, just as light rays can. When matter absorbs infra-red rays, its particles gain mechanical energy. When an object radiates infra-red rays, its particles lose mechanical energy.